CHAPTER 7

HYDRO-ELECTRIC MACHINES

* * * * *

7.1 HYDRO–MECHANICAL EQUIPMENT

Hydro-mechanical equipments are defined as those equipments, which convert either hydraulic energy into mechanical energy or mechanical energy into hydraulic energy. *For example;* hydraulic turbine

7.1.1 Hydro–Mechanical Installation in Powerhouse

For the production of the electricity from the water different kinds of hydro–mechanical and hydro–electric equipments are installed in the powerhouse, such as hydraulic turbine, generator, etc. Depending upon the shape, size, working principle, different types of turbines and generators are installed in powerhouse. For effective and economical use of hydro–mechanical instruments, they are installed on proper place in the powerhouse.

7.1.2 Types of Turbines, Pelton, Francis, Kaplan and Bulb Turbines and Their Performance Characteristics

7.1.2.1 Classification of Turbines

1. **Based on pressure**

The water flowing through the penstocks has always some pressure head, besides a kinetic head. At the inlet to the turbine runner, this pressure head can be completely converted into kinetic head in the form of jet of water from one or more nozzles and hitting the wheel vanes. In such a case, the free jet will be at atmospheric pressure, before as well as after striking the vanes. The turbines in which such a design is adopted are known as pressure–less or impulse turbine Pelton wheel belongs to this category.

On the other hand, a turbine can also be made to rotate under the action of water flowing under pressure through the runner. In such turbines the penstocks, inlet passage to the runner, passage between the runner vanes, all form a continuous passage for flow under a pressure which continuously decreases from inlet to outlet. The turbine runner directly converts both kinetic energy as well as the pressure energy into mechanical energy. Such turbines are called reaction or pressure turbines. Francis, propeller, Kaplan turbines belong to this category.

2. **Based on head**

The difference in elevation of water surface between u/s and d/s of the turbine is the head under which the turbine acts.

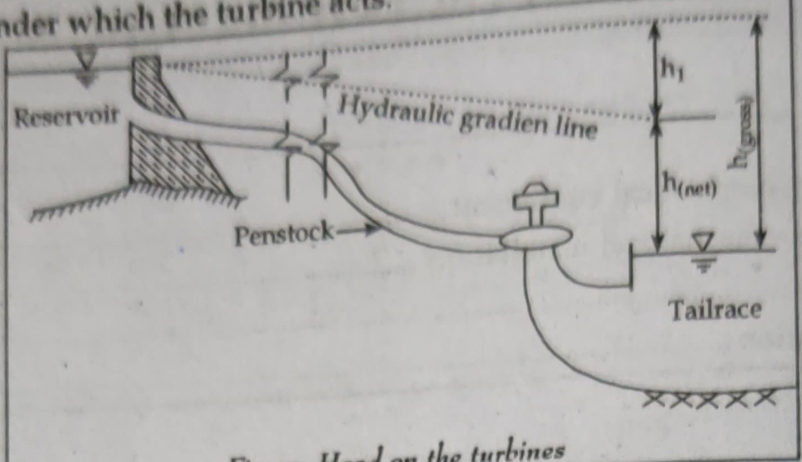


Figure: Head on the turbines

Masongi suggests the following ranges;

Low head : 2–15 m
Medium head : 15–50 m
High head : 50 m onwards

We would like to slightly modify the ranges as;

Low head : 2–15 m
Medium head : 16-70 m
High head : 71–500 m
Very high head: 500 m onwards

Now,

For low head : propeller/kaplan turbines are used.
For medium head : kaplan/francis turbines are used.
For high head : francis/pelton turbines are used.
For very high head : pelton turbine is used.

3. **Based on flow direction**

Three orthogonal directions in the turbine flow can be described as radial, axial and tangential with respect to the wheel.

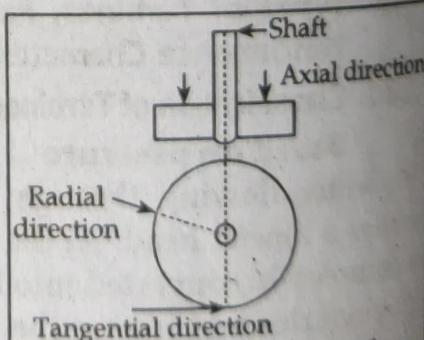


Figure: Flow directions in turbines

Sometimes the flow direction can change between inlet and outlet. It can be radial flow at the inlet and axial flow at the outlet. Such a flow is termed as mixed flow.

If the flow is neither parallel to the axis, nor perpendicular to it, it may be called as diagonal flow.

Types	Flow direction
Francis	Radial inward or mixed
Pelton	Tangential
Propeller/Kaplan	Axial
Deriaz	Diagonal

4. **Based on discharge**

Types	Discharge
Pelton	Low
Francis	Medium
Kaplan	High

5. **Based on power**

We have,

$$P = \eta \gamma Q h \text{ (kW)} \quad (1)$$

where, η is overall efficiency of turbine

Q is discharge $(m^3/sec.)$

h is effective head (m)

γ unit weight of water = $1000\ kg/m^3 = 1\ gm/cm^3 = 10\ kN/m^3$

Types	P (hp)
Kaplan	up to 150000
Pelton	up to 330000
Francis	up to 820000

6. **Based on speed**

Since, the generator and turbine are directly coupled; the rated speed of the turbine is the synchronous speed of the generator, given by;

$$N = \frac{120\ f}{N_p}$$

where, N is speed (rpm)

f is frequency of generation (usually, 50 hz = 50 cps)

N_p is number of pole of the generator

Thus, the turbine speed is determined by the generator speed. Moreover, since f and N_p are constants for any selected generators, N has also be constant. This is the basic requirement for the turbine governing. So, turbines are never classified by their actual speed, but always on the basis of the specific speed.

7. **Based on specific speed**

The specific speed for the turbine is;

$$N_s = \frac{N\sqrt{P}}{h^{\frac{5}{4}}} \quad (1)$$

where, N_s = rpm

N = rpm

P = HP

h = m

It is defined as the speed at which the machine produces 1 hp under 1 m head. It is an important parameter for the design of the turbines as it includes the three basic parameters, *viz.*, speed, power and head of the turbine. Also specific speed is related to the shape of turbine.

Types		Specific speed (rpm		
		Slow	Medium	Fast
Pelton	10-35	4-15	16-30	31-70
Francis	60-300	60-150	151-250	251-400
Kaplan	300-1000	300-450	451-700	701-1100

7.1.2.2 Turbine

Hydraulic turbines, coupled with the generators, achieve the main objective of converting water energy into electric power. The water, flowing through the turbines, impacts its energy to the runner of the turbine and makes it rotate the shaft of the runner is directly coupled with the generator shaft, thus providing the necessary mechanical energy to the generator.

Hence, turbine converts the energy available at the flow into the mechanical energy. If this energy is used to rotate the shaft of generator, then electricity could be produced.

7.1.2.3 Types of Turbines

1. Impluse turbine (pelton wheel)

Pelton wheel or Pelton turbine is a tangential flow impulse turbine. This turbine is used for high heads and is named after L. A. Pelton. The water strikes the bucket along the tangent of the tangent of the runner. The energy available at the inlet of the turbine is only kinetic energy. The pressure at the inlet and outlet is atmospheric pressure. The nozzle increases the kinetic energy of the water flowing through the penstock. At the outlet of the nozzle, the water comes out in the form of a jet and strikes the buckets (vanes) of the runner. Pelton wheel turbine is used for high heads. Pelton wheel turbine has a specific speed less than 30 (S.I) for single jet and between 30 and 60 (S.I) for multi-jet.

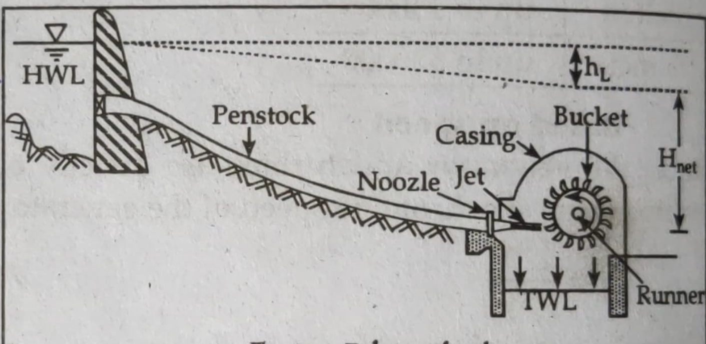


Figure: Pelton wheel

Working principle of Pelton turbines

From the head race in the mountains water is conveyed to the turbines installed in the power house through the penstocks. The lower end of the penstock is joined with a nozzle in the turbine casing. Water is delivered by the nozzle at a high velocity on the buckets. These buckets are mounted on the periphery of a circular wheel (also known as runner) which is generally mounted on a horizontal shaft. The quantity of water coming out of the nozzle or nozzles can be controlled

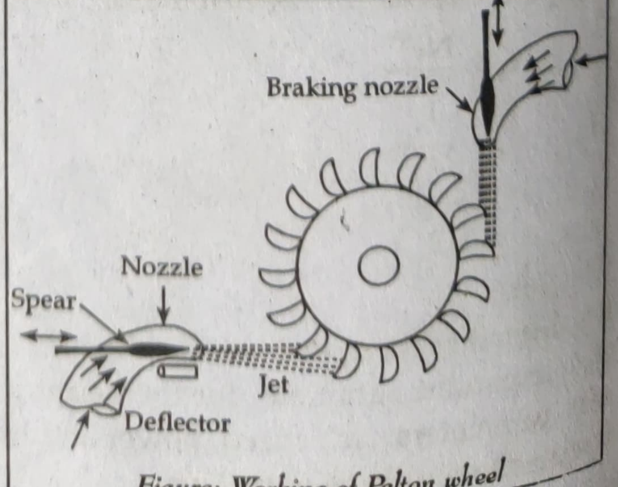


Figure: Working of Pelton wheel

by regulators (governing arrangement) in case of big installations and by hand wheels in ca se of small installations. The impact of water on the buckets causes the runner to rotate, thus develops mechanical energy. After doing work on the buckets water is discharged in the tail race. Being impulse turbine it must run at atmospheric pressure and therefore, these are located above the tail race. The buckets are so shaped that water enters tangentially in the middle and discharges backward and flows again tangentially in both the direction to avoid thrust on the wheel (as shown in the line sketch). Actually the jet is deflected by 160°. To produce electric energy these are coupled with the electric generators.

Components of Pelton wheel

a) **Nozzle and flow regulating arrangement**

The amount of water striking the buckets is controlled by providing a spear in the nozzle. The spear is a conical needle operated in the axial direction depending up on the size of the unit. When the spear is pushed forward, the amount of water striking the runner is reduced and when the spear is pushed back, the amount of water striking the runner increases.

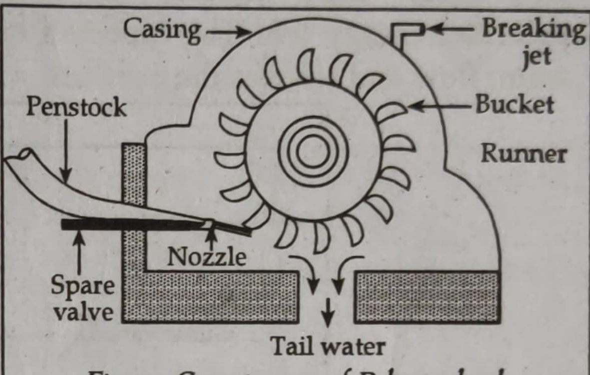


Figure: Components of Pelton wheel

b) **Runner and buckets**

Runner consists of a circular disc on the periphery of which a number of buckets evenly spaced are fixed. The space of the buckets is of a double hemispherical cup or bowl. Each bucket is divided into two symmetrical parts by dividing wall which is known as splitter. The splitter divides the jet into two equal parts. The buckets are shaped in such a way that the jet gets deflected through 160° or 170°. The buckets are made of cast iron, cast steel bronze or stainless steel depending upon the head at the inlet of the turbine.

c) **Casing**

The function of casing is to prevent the splashing of water and to discharge water to tail race. The casing of Pelton wheel does not perform any hydraulic function.

d) **Breaking jet**

When the nozzle is completely closed by moving the spear in the forward direction, the amount of water striking the runner reduces to zero. But the runner due to inertia goes on revolving for a long time. To stop the runner in a short time, a small nozzle is provided which directs the jet of water on the back of vanes. This jet of water is called breaking jet.

2. **Francis (reaction) turbine**

The Francis turbine is a type of water turbine that was developed by James B. Francis in Lowell, Massachusetts. It is an inward-flow reaction turbine that combines radial and axial flow concepts. Francis turbines are the most common water turbine in use today.

The Francis turbine is a type of reaction turbine, a category of turbine in which the working fluid comes to the turbine under immense pressure and the energy is extracted by the turbine blades from the working fluid. A part of the energy is given up by the fluid because of pressure changes occurring in the blades of the turbine, quantified by the expression of degree of reaction, while the remaining part of the energy is extracted by the volute casing of the turbine. At the exit, water acts on the spinning cup-shaped runner features, leaving at low velocity and low swirl with very little kinetic or potential energy left. The turbine's exit tube is shaped to help decelerate the water flow and recover the pressure.

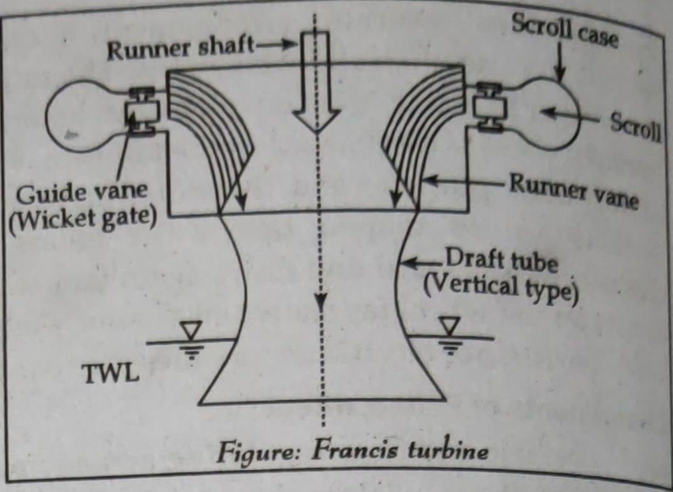


Figure: Francis turbine

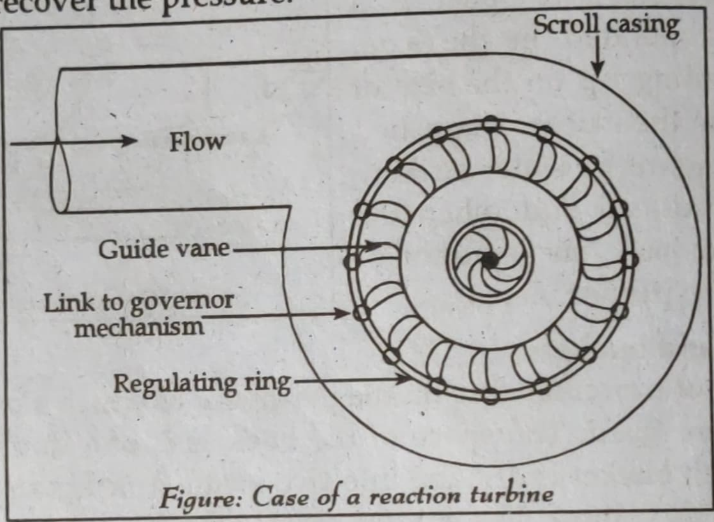


Figure: Case of a reaction turbine

Components of Francis Turbine

A Francis turbine consists of the following main parts:

i) **Spiral casing**

The spiral casing around the runner of the turbine is known as the volute casing or scroll case. Throughout its length, it has numerous openings at regular intervals to allow the working fluid to impinge on the blades of the runner. These openings convert the pressure energy of the fluid into momentum energy just before the fluid impinges on the blades. This maintains a constant flow rate despite the fact that numerous openings have been provided for the fluid to enter the blades, as the cross-sectional area of this casing decreases uniformly along the circumference.

ii) **Guide or stay vanes**

The primary function of the guide or stay vanes is to convert the pressure energy of the fluid into the momentum energy. It also serves to direct the flow at design angles to the runner blades.

iii) **Runner blades**

Runner blades are the heart of any turbine. These are the centers where the fluid strikes and the tangential force of the impact causes the shaft of the turbine to rotate, producing torque. Close attention in design of blade angles at inlet and outlet is necessary, as these are major parameters affecting power production.

iv) **Draft Tube**

The draft tube is a conduit that connects the runner exit to the tail race where the water is discharged from the turbine. Its primary function is to reduce the velocity of discharged water to minimize the loss of kinetic energy at the outlet. This permits the turbine to be set above the tail water without appreciable drop of available head.

Difference between an impulse and reaction turbine

	Impulse turbine (Pelton)	Reaction turbine (Francis)
i)	Available energy of water is first converted into kinetic energy.	Available energy of water is not converted from one from to another.
ii)	The water flows through the nozzles and impinges on the buckets, which are fixed to the outer periphery of wheel.	The water is guided by the guide vanes (blades) to flow over the moving vanes.
iii)	The water impinges on the buckets, with kinetic energy.	The water glides over the moving vanes, with pressure energy.
iv)	The pressure of the flowing water remains unchanged, and is equal to the atmospheric pressure.	The pressure of the flowing water is reduced after gliding over the vanes.
v)	It is not essential that the wheel should run full moreover; there should be free access of air between the vanes and the wheel.	It is essential that the wheel should always run full and kept full of water.
vi)	The water may be admitted over a part of circumference or over the whole circumference of the wheel.	The water must be admitted over the whole circumference of the wheel.
vii)	It is possible to regulate the flow without loss.	It is not possible to regulate the flow without loss.
viii)	The work is done by the change in the kinetic energy of the jet.	The work is done partly by the change in velocity head, but almost entirely by change in pressure head.

3. **Kaplan turbine**

The Kaplan turbine is a propeller-type water turbine which has adjustable blades. It was developed in 1913 by Austrian professor Viktor Kaplan, who combined automatically adjusted propeller blades with automatically adjusted wicket gates to achieve efficiency over a wide range of flow and level. The Kaplan turbine was an evolution of the Francis turbine. Its invention allowed efficient power production in low-head applications which was not possible with Francis turbines. The head ranges from 10–70 meters and the output ranges from 5 to 200 MW. Runner diameters are between 2 and 11 meters. Kaplan turbines are now widely used throughout the world in high-flow, low-head power production. It is an axial flow reaction turbine. This operates in an entirely closed conduit to tailrace. Kaplan turbine is employed, where a large quantity of water is available.

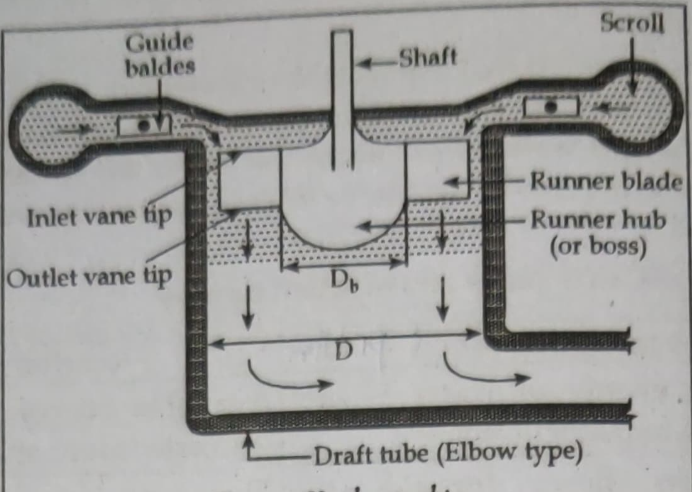


Figure: Kaplan turbine

Working of Kaplan turbine

The working head of water is low so large flow rates are allowed in the Kaplan Turbine. The water enters the turbine through the guide vanes which are aligned such as to give the flow a suitable degree of swirl determined according to the rotor of the turbine. The flow from guide vanes pass through the curved passage which forces the radial flow to axial direction with the initial swirl imparted by the inlet guide vanes which is now in the form of free vortex. The axial flow of water with a component of swirl applies force on the blades of the rotor and loses its momentum, both linear and angular, producing torque and rotation (their product is power) in the shaft. The scheme for production of hydroelectricity by Kaplan turbine is same as that for Francis turbine.

Kaplan turbine consists of the following parts:

a) Spiral or scroll air tight casing
b) Guide mechanism
c) Runner and main shaft
d) Draft tube
e) Governor

i) **Runner**

The runner of a Kaplan turbine is known as boss, which is nothing but an extension of the shaft at its lower end.

Discharge through the turbine is, $Q = V_f \times \frac{\pi}{4}(D^2 - D_b^2)$

where, D is diameter of turbine.

D_b is diameter of the boss.

V_f is velocity of flow at inlet.

ii) **Draft tube**

It is a pipe, which connects the turbine and the tail race or outlet channel, through which the water exhausted from the runner, flows to the outlet channel.

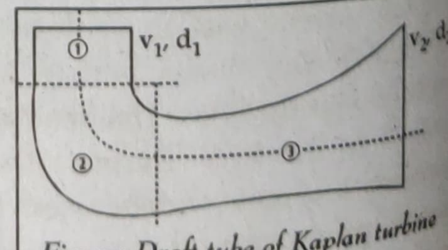


Figure: Draft tube of Kaplan turbine (elbow type)

It has following functions;

- It enables the turbine to be placed over the tail race, so that the turbine may be inspected properly.

- To convert the kinetic energy (V_1^2) of the water, exhausted by the runner into pressure energy in the tube.

The angle of the conical draft tube is usually kept with angle 5-6°, so as to minimize the vortex formation of flow inside the draft tube, which may cause the excessive head loss. In order to increase the efficiency of the turbine, V_2 should be decreased as much as possible in conical draft tube, so it may need to lower the draft tube very much deep in the water, which may not be economical because of deep excavation.

In such case, elbow, the draft tube is considered where exit velocity could be adjusted with increasing the size of the diffuser avoiding much excavation work.

Part I

It is the entrance cone of the draft tube, where the flow coming through the runner of the turbines decelerates. This will cause the conversion of kinetic energy of the flow into the pressure energy.

Part II

It is the portion of the draft tube, which will cause the change of direction of flow towards the tailrace channel. The shape is designed to follow the streamline of the flow and slightly increased at the end portion to avoid the flow separation. This is the transition portion of the draft tube, where the section from the circular shape changes to oval shape.

Part III

It is the diffuses part of the draft tube, which changes from oval shape to rectangular shape having round corners with increasing the section area. Area at the end of the diffuser is designed in such a way that the flow velocity minimum at the exit point.

4. Bulb (Capsule) turbine

The bulb turbine is a reaction turbine of Kaplan type which is used for extremely low heads. The characteristic feature of this turbine is that the turbine components as well as the generator are housed inside a bulb, from which the name is developed. The main difference from the Kaplan turbine is that the water flows in a mixed axial-radial direction into the guide vane cascade and not through a scroll casing. The guide vane spindles are normally inclined to 600 in relation to the turbine shaft and thus results in a conical guide vane cascade contrary to other types of turbines. The runner of a bulb turbine may have different numbers of blades depending on the head and water flow. The bulb turbines have higher full-load efficiency and higher flow capacity as compared to Kaplan, turbine. It has a relatively lower construction cost. The bulb turbines can be utilized to tap electrical power from the fast flowing rivers on the hills.

The Bulb Tubular turbine is the best selection for exploitation of tidal power and hydraulic power with extremely low water head and extremely large discharge. It has large discharge, high specific speed and high efficiency, and needs less excavation in civil works.

Our tubular turbines are ranging from 2 to 18 m in water head, 50 kW to 30 MW in capacity, and 0.8 to 6.5 m in runner diameter.

5. **Turgo turbine**

The Turgo turbine is an impulse water turbine designed for medium head applications. Operational Turgo turbines achieve efficiencies of about 87%. In factory and lab tests Turgo Turbines perform with efficiencies of up to 90%.Developed in 1919 by Gilkes as a modification of the Pelton wheel, the Turgo has some advantages over Francis and Pelton designs for certain applications.

First, the runner is less expensive to make than a Pelton wheel. Second, it doesn't need an airtight housing like the Francis. Third, it has higher specific speed and can handle a greater flow than the same diameter Pelton wheel, leading to reduced generator and installation cost.

Turgos operate in a head range where the Francis and Pelton overlap. While many large Turgo installations exist, they are also popular for small hydro where low cost is very important.

Like all turbines with nozzles, blockage by debris must be prevented for effective operation. The Turgo turbine is an impulse type turbine; water does not change pressure as it moves through the turbine blades. The water's potential energy is converted to kinetic energy with a nozzle. The high speed water jet is then directed on the turbine blades which deflect and reverse the flow. The resulting impulse spins the turbine runner, imparting energy to the turbine shaft. Water exits with very little energy. Turgo runners may have an efficiency of over 90%.

7.1.2.4 Performance of Turbines

We have already known that impulse and reaction turbines will work under a constant head, speed and output. But in actual practice, these assumptions rarely prevail. It is this essential to review the nature of such variations, which generally take place though there are many types of variations, yet the following are important from the subject of point of view.

i) Keeping the discharge constant, the head of water and output may vary In such cases the speed should be adjusted, so that there is no appreciable change in efficiency.
ii) Keeping the head of water and speed constant, the output may vary. In such cases, the discharge of the turbine should be adjusted.
iii) In turbine, working under low heads, the head of water and speed may vary. Although the speed is allowed to fluctuate within narrow permissible limits, yet the head may vary up to 50%.
iv) Keeping the head of water and discharge constant, the speed may vary by adjusting the load on the turbine.

7.1.2.5 Characteristics of Turbines

1. **Unit power**

The power developed by a turbine, working under a head of 1 m is known as unit power.

Let, H is the head of water, under when the turbine is working.
P is power developed by the turbine under head H.
Q is discharge through the turbine under a head H.
P_u is power developed by same turbine under unit head.

N_u is speed of same turbine under unit head.

Q_u is discharge through same turbine under unit head.

v is tangential velocity of the runner.

V is velocity of water.

N is speed of the turbine runner under a head H.

Now,

$$V = C_v\sqrt{2gH} \qquad [\therefore C_v = 1]$$

$$Q = aV = a\sqrt{2gH}$$

Then,

$$P = \eta\gamma QH = \eta\gamma\left(a\sqrt{2gH}\right)H$$

or, $P \propto H^{\frac{3}{2}}$

or, $P = P_u H^{\frac{3}{2}}$

$$\therefore \quad P_u = \frac{P}{H^{\frac{3}{2}}} \qquad (1)$$

2. **Unit speed**

The speed of the turbine, working under a head of 1 m, is known as unit speed. Now, we have;

$$V = \sqrt{2gH}$$

But,

$$v \propto V \qquad [\therefore v = 0.46\ V]$$

or, $v \propto \sqrt{H}$

So,

$$N = \frac{60\ v}{\pi D}$$

or, $N \propto v$

or, $N \propto \sqrt{H}$

or, $N = N_u\sqrt{H}$

$$\therefore \quad N_u = \frac{N}{\sqrt{H}} \qquad (2)$$

3. **Unit discharge**

The discharge of a turbine, working under a head of 1 m is known as a unit discharge. We have,

$$Q = aV = a\sqrt{2gH}$$

or, $Q \propto \sqrt{H}$

or, $Q = Q_u\sqrt{H}$

$$\therefore \quad Q_u = \frac{Q}{\sqrt{H}} \qquad (3)$$

Significance of Unit Power, Unit Speed and Unit Discharge

Let's us find out the behavior of a turbine, when it is put to work under different heads of water as discussed as follows;

1. Significance of unit power

Let, H is head of water, under which turbine is working.

P is power of turbine under head H.

P_1 is power of turbine under head H_1.

We have,

$$P \propto H^{\frac{3}{2}}$$

$$P_1 \propto H_1^{\frac{3}{2}}$$

So, $$\frac{P}{P_1} = \frac{H^{\frac{3}{2}}}{H_1^{\frac{3}{2}}}$$

$$\therefore \quad P_1 = P \times \left(\frac{H_1}{H}\right)^{\frac{3}{2}} \qquad (1)$$

2. Significance of unit speed

Let, H is head of water, under which the turbine is working.

Q is discharge of turbine under a head H.

Q_1 is discharge of turbine under a head H_1.

We have,

$$N \propto \sqrt{H}$$

$$N_1 \propto \sqrt{H_1}$$

so, $$\frac{N}{N_1} = \frac{\sqrt{H}}{\sqrt{H_1}}$$

$$\therefore \quad N_1 = P \times \left(\frac{H_1}{H}\right)^{\frac{1}{2}} \qquad (2)$$

3. Significance of unit discharge

Let, H is head of water, under which the turbine is working. We have,

$$Q \propto \sqrt{H}$$

$$Q_1 \propto \sqrt{H_1}$$

so, $$\frac{Q}{Q_1} = \frac{\sqrt{H}}{\sqrt{H_1}}$$

$$\therefore \quad Q_1 = P \times \left(\frac{H_1}{H}\right)^{\frac{1}{2}} \qquad (3)$$

7.1.2.6 Characteristics Curves of Turbines

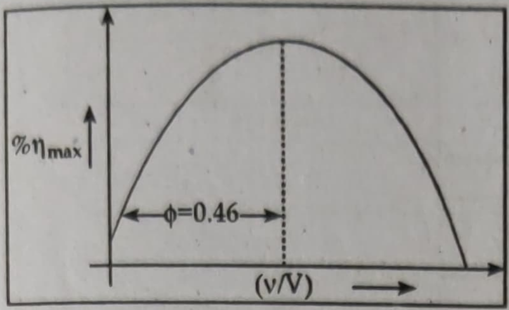
The characteristics curves are generally drawn for constant head or constant speed of the turbine runner.

Sometimes, these curves are also drawn for various gate opening (G.O.) (i.e., when the gate is fully open, 0.75 open, 0.5 open, etc.)

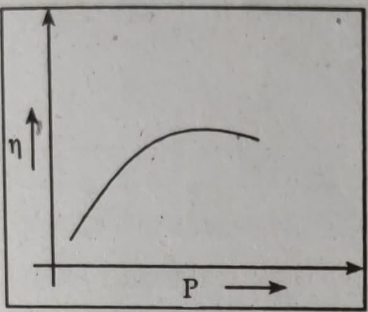
1. **Characteristics for Pelton wheels**

i) **Constant head**

a) u/v vs $\%\eta_{max}$

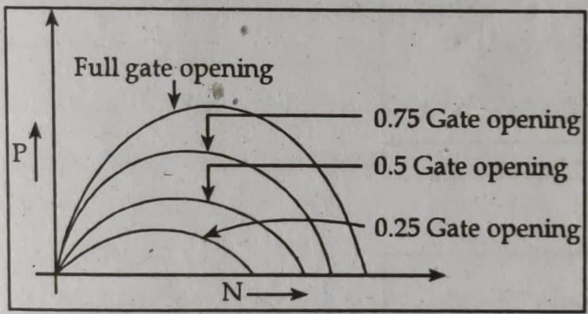


b) Power vs efficiency

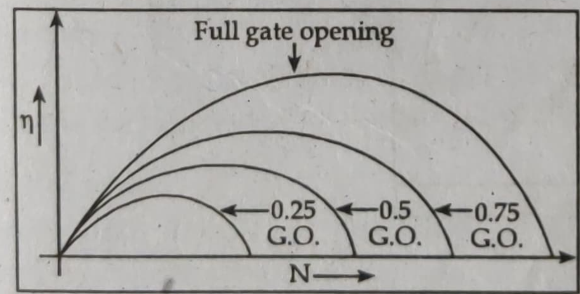


ii) **For varying gate opening**

a) Speed vs power



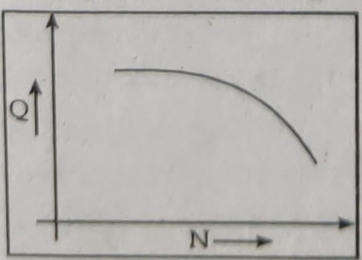
b) Speed vs efficiency



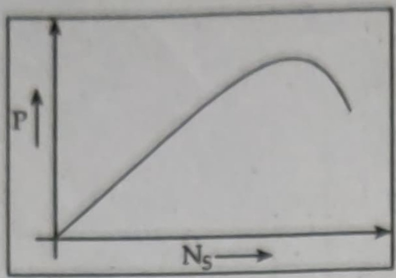
2. **Characteristics curves for Francis Turbines**

i) **For unit speed**

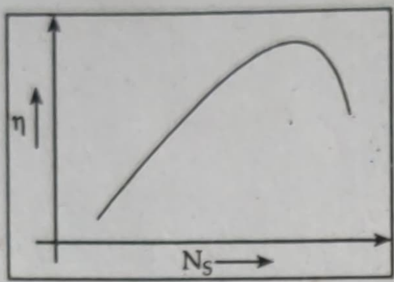
a) Unit speed vs discharge



b) Unit speed vs power

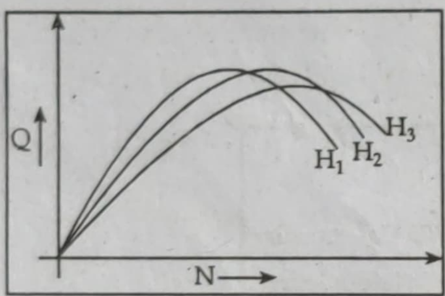


c) Unit speed vs efficiency

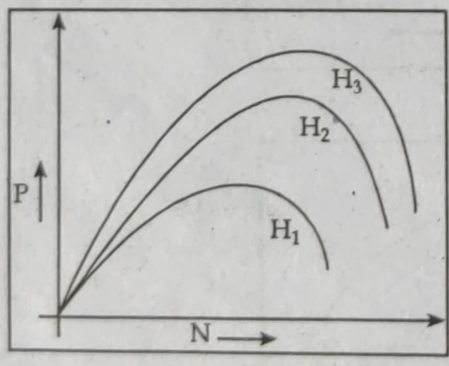


ii) **For speed with varying heads**

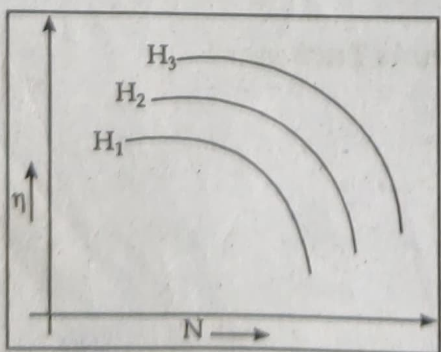
a) Speed vs discharge



b) Speed vs power

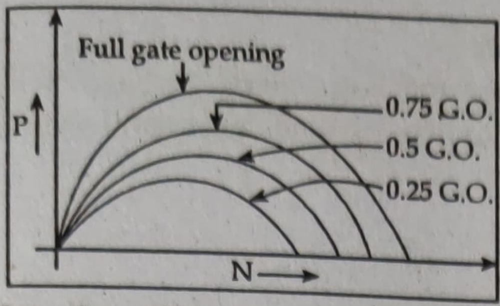


c) Speed vs efficiency

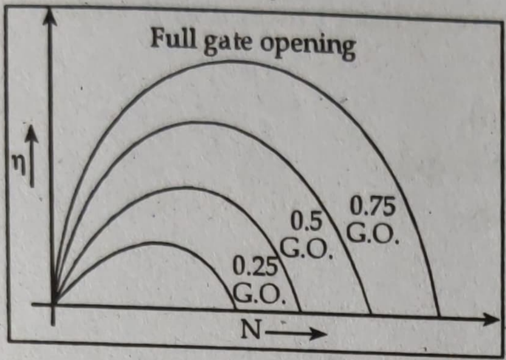


iii) **For varying gate opening**

a) Speed vs power



b) Speed vs efficiency



7.1.3 Selection of Turbines and Their Specific Speed, Turbine Setting

7.1.3.1 Selection of turbines

For turbine selection and plant capacity determination requires the details information on head and possible plant discharge. In theoretical, the turbine output E can be expressed mathematically as;

$$E = F(H, Q, TW, D, N, H_s, P_{max})$$

Following are the factors to be considered while selecting turbine;

1. **Available head and its fluctuations**
   i) Very high head > 350 m : Pelton turbine
   ii) High head (150–350 m) : Pelton or Francis
   iii) Medium head (60–150 m) : Francis turbine
   iv) Low head (< 60 m) both : Both Kaplan and Francis

2. **Efficiency**

The turbine which gives highest overall efficiency for various operating condition should be selected.

3. **Specific speed**

It is necessary high specific speed where head is low and output is large, otherwise the rotational speed will be low, which means cost of turbo generator and powerhouse will be high. But in practice, no need of choosing a high value specific speed for high installation because even with low specific speed high rotational speed can be attained with medium capacity plant.

4. **Rotational speed**

It depends upon specific speed, but in practice it should be attains high value.

5. **Water quality**

Quality of water is more crucial for reactive turbine than reaction turbine.

6. **Conveyance or maintenance**

Impulse turbine has less cost of maintenance than that of reaction turbine.

7. **Deposition of turbine shaft**

Vertical shaft arrangement is better for large sized turbine, it is universally adopted. But, in case of large size impulse turbine, horizontal shaft arrangement is almost employed.

7.1.3.2 Turbine Speeds

1. **Specific speed**

It is defined as the specific speed at an imaginary turbine, identical with the given turbine which will develop a unit power under a unit load.

Let, N_s is specific speed of turbine
N is speed of the runner (rpm)
D is diameter of turbine runner (m)
Q is discharge through turbine
V_f is velocity of flow
V is absolute velocity of water
$\overline{V}$ is tangential velocity of the runner
b is width of the turbine runner
P is power develop (HP)

Now,

$$\overline{V} \propto V$$

or, $$\overline{V} \propto \sqrt{2gh} \qquad (\because V = \sqrt{2gh})$$

or, $$\overline{V} \propto \sqrt{H} \qquad (1)$$

We have,

$$\overline{V} = \frac{\pi DN}{60}$$

or, $$D \propto \frac{\overline{V}}{N}$$

or, $$D \propto \frac{\sqrt{H}}{N} [\because \overline{V} \propto \sqrt{H} \text{ from equation (1)}] \qquad (2)$$

Also,

$$Q = \pi DbV_f$$

But, $b \propto D$

and, $V_f \propto \sqrt{2gh} \propto \sqrt{H}$

$\therefore$ $$Q \propto \pi DD\sqrt{H} \qquad (\because b \propto D, V_f \propto \sqrt{H})$$

or, $$Q \propto D^2\sqrt{H} \qquad (3)$$

or, $$Q \propto \frac{H}{N^2} \times \sqrt{H}$$

or, $$Q \propto \frac{H^{\frac{3}{2}}}{N^2}$$

Again,

$$P = \eta rQH$$

or, $$P \propto QH \qquad [\eta = \text{efficiency}]$$

or, $P \propto \frac{H^{\frac{3}{2}}}{N^2} \times H$ $\left[\because Q \propto \frac{H^{\frac{3}{2}}}{N^2}\right]$

or, $P \propto \frac{H^{\frac{5}{2}}}{N^2}$

or, $N^2 \propto \frac{H^{\frac{5}{2}}}{P}$

or, $N \propto \frac{N^{\frac{5}{4}}}{\sqrt{P}}$

or, $N = N_s \frac{N^{\frac{5}{4}}}{\sqrt{P}}$

or, $N_s = \frac{N\sqrt{P}}{H^{\frac{5}{4}}}$

where, P in 'HP'.

H in 'm' and,

N in 'rpm'.

This is the required relation between specific speed of turbine and runner speed.

Specific speed for different turbines

i) For Francis turbine

$$N_s = \frac{2400}{\sqrt{H}}$$

[T.L. while formula to calculate N_s for head 18 m to 360 m of Francis turbine is, $N_s = \frac{1540}{\sqrt{H}}$]

ii) For fixed blade propeller turbine (head < 18 m)

$$N_s = \frac{1030}{H^{\frac{1}{4}}}$$ [U.S.B.R. formula]

iii) For adjustable blade propeller turbine *i.e.,* Kaplan turbine,

$$N_s = \frac{1475}{H^{\frac{1}{3}}}$$

iv) Single jet Pelton turbine

$$N_s = \frac{260\sqrt{n}}{\frac{D}{d}}$$

The specific speeds of different types of turbine are shown below;

Types of turbine	Specific speed
Less than 30	Single jet Pelton turbine
30-50	Multi jet Pelton turbine
50-260	Francis turbine
260-860	Kaplan turbine

2. Synchronous speed

If the turbine is directly connected to the generator, the turbine speed N must be synchronous speed. For the turbine speed n to be synchronous, the following equation must be fulfilled:

$$N = \frac{120\,f}{N_p}$$

where, N is rotational speed

f is electric frequency in Hertz (50 Hz in Nepal)

N_p is number of generator pole

3. Runway speed

If the external load on the machine suddenly drops to zero and the governing mechanism fails at the same time, the turbine will tend to race up to the maximum possible speed, known as runway speed.

4. Speed factor

It is the ratio of peripheral speed $\overline{V}$, of the buckets or vanes at the nominal diameter 'D', to the theoretical velocity of water under the effective head 'H', acting on the turbine,

$$\text{Speed factor } (\phi) = \frac{\overline{V}}{\sqrt{2gH}}$$

But, $\overline{V} = \frac{\pi DN}{60}$

$$\therefore \quad \phi = \frac{DN}{84.6\sqrt{H}}$$

7.1.3.3 Turbine Setting

The location of turbine with respect to the head and tail water levels is known as setting of turbine.

If, σ is Thomas cavitation number

σ_c is minimum value of σ

H is effective head of runner

$H_b = 10.1$ m [At sea level and 20°C] $= H_a - H_v = 10.3 - 0.2 = 10.1$ m

$\therefore$ Maximum permissible turbine setting,

$H_{s,\,max} = H_b - \sigma_c H = H_a - H_V - \sigma_c H$

where, H_a = Atmospheric pressure

H_V = Vapour pressure

The value of σ_c is computed from following formulas,

i) **For Francis turbine**

$$\sigma_c = 0.0432\left(\frac{N_s}{100}\right)^2 = 0.625\left(\frac{N_s}{380.78}\right)^2$$

ii) **For propeller turbine**

$$\sigma_c = 0.28 + 0.0024\left(\frac{N_s}{100}\right)^3$$

iii) **For Kaplan turbine**

$\sigma_c = 1.1 \times \sigma_c$ of propeller turbine

NOTE

Here, above formula is adopted for,

$$N_s = \frac{N\sqrt{P_{kW}}}{H^{\frac{5}{4}}} \text{ (by taking P in kW)}$$

If we take P in HP, following formula is used for calculate σ_c,

i) **For Francis turbine**

$$\sigma_c = 0.032 \left(\frac{N_s}{100}\right)^2$$

where, $N_s = \frac{N\sqrt{P_{HP}}}{H^{\frac{5}{4}}}$ (by taking P in HP)

ii) **For propeller**

$$\sigma_c = 0.28 + \frac{1}{660}\left(\frac{N_s}{100}\right)^3$$

where, $N_s = \frac{N\sqrt{P_{HP}}}{H^{\frac{5}{4}}}$

7.1.4 Preliminary Design of Francis and Pelton Turbine

7.1.4.1 Design of Pelton Turbine

Let, D is diameter of runner wheel.
d is diameter of jet nozzle.
W is width of the bucket.
N is design speed.
N_s is specific speed.

i) The velocity of jet at inlet is given by;

$$V_1 = C_v\sqrt{2gH}$$

where, C_v is co-efficient of velocity = 0.98 or 0.99

ii) The velocity of the jet (tangential velocity of the wheel) in the turbine,

$$\overline{V} = \phi\sqrt{2gH}$$

$$\therefore \quad \phi = \frac{\overline{V}}{\sqrt{2gH}}$$

where, ϕ is speed factor (speed ratio) = 0.43 to 0.48

iii) The angle of deflection of the jet through bucket is taken as 135°, if angle of deflection is not given.

iv) The mean diameter on pitch diameter D of the Pelton wheel is given by;

$$\overline{V} = \frac{\pi ND}{60}$$

$$\text{or,} \quad D = \frac{60\overline{V}}{\pi N}$$

$$\text{But,} \quad \phi = \frac{\overline{V}}{\sqrt{2gH}}$$

and, $\overline{V} = \frac{\pi ND}{60}$

$\therefore \quad \phi = \frac{DN}{84.6\sqrt{H}}$

v) Jet ratio
Ratio of the pitch diameter (D) of Pelton wheel to the diameter of jet (d).

Jet ratio (m) $= \frac{D}{d}$ [Generally taken as 10–15]

vi) Number of bucket on a runner,

$$N_b = 15 + \frac{D}{2d}$$

and, Bucket spacing, $S = \frac{\pi D}{N_b}$

vii) Working proportion

Axial width of the bucket, (B) = 3d to 4d
Radial length, (L) = 2d to 3d
Depth, (T) = 0.8d to 1.2d

viii) Number of jet
It is obtained by dividing the total rate of flow through the turbine by the rate of flow of water through the single jet.

Example 7.1

Design a Pelton wheel turbine for a hydropower plant having net head of 310 m and discharge of 5 m³/sec. Take efficiency of the turbine as 90%. What will be the specific speed of such turbine? **[2071 Chaitra]**

Solution:

Given that;

$H = 310$ m
$\eta = 90\%$
$Q = 5\ m^3/sec.$

Now,

Velocity of jet, $V_1 = C_v\sqrt{2gH}$

Take $C_v = 0.98$;

$\therefore \quad V_1 = 0.98 \times \sqrt{2 \times 9.81 \times 310} = 76.42\ m/sec.$

Now,

$Q = AV_1$

or, $5 = \frac{\pi d^2}{4} \times V_1$

or, $d = 0.288$ m = diameter of jet

Take $m = \frac{D}{d} = 15$; *i.e.*, 10–15,

$\therefore$ Diameter of runner (D) = d × 15 = 4.32 m

Number of bucket of runner,

$$N_b = 15 + \frac{D}{2d} = 15 + \frac{4.32}{2 \times 0.288} = 22.50 = 23 \text{ numbers}$$

$$\text{Bucket spacing (S)} = \frac{\pi D}{N_b} = \frac{3.1416 \times 4.32}{23} = 0.59 \text{ m}$$

Design speed or rotational speed,

$$N = \frac{60\overline{V}}{\pi D}$$

But, $\overline{V} = \phi\sqrt{2gH}$

Take $\phi = 0.46(0.43\text{–}0.48)$;

∴ $\overline{V} = 0.46 \times \sqrt{2g \times 310} = 35.87 \text{ m/sec.}$

so, $N = \frac{60\overline{V}}{\pi D} = \frac{60 \times 35.87}{3.1416 \times 4.32} = 158.6 \text{ rpm}$

$$\text{Number of poles } (N_p) = \frac{120 f}{N} = \frac{120 \times 50}{158.6} = 37.88 = 38 \qquad [\because f = 50 \text{ hz}]$$

so, $\text{Corrected, } N = \frac{120 f}{N_p} = \frac{120 \times 50}{38} = 157.89 \text{ rpm} = 158 \text{ rpm}$

Again,

$$\text{Power (P)} = \eta r Q H = 90\% \times 9.81 \times 5 \times 310 = 13684.95 \text{ kW}$$

$$= \frac{13684.95}{0.746} \text{ HP} = 18344.437 \text{ HP}$$

∴ $\text{Corrected, } N_s = \frac{N\sqrt{P}}{H^{\frac{5}{4}}} = \frac{158\sqrt{18344.437}}{(310)^{\frac{5}{4}}} = 16.45 \approx 17 \text{ rpm}$

∴ Specific speed of the turbine $(N_s) = 17$ rpm

Example 7.2

A hydroelectric plant built for design of H = 30 m should develop power output 20000 HP. Determine the number of turbine units, of turbine having specific speed of $N_s = 600$ is to be used at the normal operating speed of N = 230 rpm.

Solution:

Given that;

H = 30 m

Rotational speed (N) = 230 rpm

Specific speed (N_p) = 600 rpm

Power output (P) = 20000 HP

Number of turbine =?

We have,

$$N_s = \frac{N\sqrt{P}}{H^{\frac{5}{4}}}$$

∴ $P = \left(\frac{N_s H^{\frac{5}{4}}}{N}\right)^2 = \left(\frac{600 \times (30)^{\frac{5}{4}}}{230}\right)^2 = 33546.71 \text{ HP}$

∴ $\text{Number of turbine required} = \frac{P_{output}}{P_{input}} = \frac{20000}{33546.71} = 0.596 = 1$

Provide 1 numbers of turbine.

$$\therefore \quad D = \frac{84.60 \times 0.679 \times \sqrt{150}}{500}$$

For setting of turbine,

$$\sigma_c = 0.625 \left(\frac{N_s}{380.78}\right)^2$$

where, N_s for P in kW

$$\therefore \quad N_s = \frac{N\sqrt{P_{kW}}}{H^{\frac{5}{4}}} = \frac{500 \times \sqrt{29797.87}}{(150)^{\frac{5}{4}}} = 164.42 \text{ rpm}$$

Alternatively;

NOTE

Directly we can change $N_{s\,(SI)}$ into $N_{s\,(metric)}$

$$\text{i.e.,} \quad N_{s\,(SI)} = \frac{N_{s\,(metric)}}{1.157} = \frac{\text{Corrected } N_s}{1.157} = \frac{190.36}{1.157} = 164.52 \text{ rpm}$$

$$\therefore \quad \sigma_c = 0.625 \left(\frac{164.52}{380.78}\right)^2 = 0.117$$

and, $H_s = H_b - \sigma_c H = 10 - 0.117 \times 150 = 7.60$ m [Take, $H_b = 10$ to 10.3 m]

$\therefore$ The turbine is set 7.60 m above tailrace.

7.1.4.3 Design of Kaplan Turbine and Propeller Turbine

For designing, the following steps followed.

i) The peripheral velocity at inlet and outlet are equal,

$$\text{i.e.,} \quad u_1 = u_2 = \frac{\pi D_0 N}{60}$$

where, D_0 is outer diameter of runner

ii) Velocity of flow at inlet and outlet are equal,

$$V_{f_1} = V_{f_2} = V_m$$

iii) Area of flow at inlet = Area of flow at outlet is equal

i.e., $A = \frac{\pi}{4}(D_0^2 - D_b^2)$

where, D_b is the diameter of bass.

iv) Discharge through the runner is,

$$Q = V_{f_1} \times \frac{\pi}{4}(D_0^2 - D_b^2)$$

v) Diameter of turbine,

$$D = \frac{84.6\ \phi\sqrt{H}}{N}$$

where, $\phi = 0.024\ N_s^{\frac{2}{3}}$

[According to P. C. Mag and K. Madhuan's for fixed blade propeller turbine,

$$\phi = 0.024\ N_s^{\frac{2}{3}}$$

and, for adjustable blade Kaplan turbine $\phi = 0.0252\ N_s^{\frac{2}{3}}$]

Example 7.4

In hydropower project, the available discharge is 340 m³/sec. under the net head of 27.5 m. If the speed of the turbine is to be 166.7 rpm and overall efficiency is 88%. Determine the type and number of unit required, if

i) Turbine of specific speed 560 rpm in SI units is selected

ii) Determine the location of turbine with respect to the tail water level, if cavitation co-efficient [σ] is 0.78, atmospheric pressure and vapour pressure are 10.3 m and 0.3 m of water head respectively. [2062 Bhadra]

Solution:

Here,

$$\text{Discharge } (Q) = 340\ m^3/sec.$$

$$\eta = 88\%$$

$$H = 27.5\ m$$

$$N_s = 560\ rpm$$

$$\sigma = 0.78$$

$$H_a = 10.3$$

$$H_v = 0.3\ m$$

$$N = 166.7\ rpm$$

Now,

i) Here, discharge is high and head is 1 to 30 m so select Kaplan type turbine,

Now,

$$\text{Total power } (P_t) = \eta rQH = 0.88 \times 9.81 \times 340 \times 27.5 = 80716.68\ kN$$

For power of each unit,

$$N_s = \frac{N\sqrt{P}}{H^{\frac{5}{4}}}$$

or, $$560 = \frac{166.7\sqrt{P}}{(27.5)^{\frac{5}{4}}}$$

or, $$P = 714754.48 \text{ kW}$$

Here, N_s is SI unit so power is in kW

$$\therefore \text{Number of units} = \frac{\text{Total power}}{\text{Power of each unit}} = \frac{80716.68}{44754.48} = 1.8 \approx 2 \text{ units}$$

ii) For Kaplan turbine, [From Thoma's condition]

$$\sigma_c = 1.1\left[0.0024\left(\frac{N_{s(SI)}}{100}\right)^3 + 0.28\right] = 1.1\left[0.0024\left(\frac{560}{100}\right)^3 + 0.28\right]$$

$$= 0.7716 < 0.78;\ i.e.,\ \sigma$$

Here, $\sigma_c < \bar{\sigma}$, so cavitation is not occur.

For no cavitation occur,

$$H_s = (H_a - H_v) - \sigma_c H$$

or, $$H_s = (10.3 - 0.3) - 0.771 \times 27.5 = 10 - 21.20 = -11.20 \text{ m}$$

Hence, for no cavitation occurs set the turbine below 11.20 m from tailrace.

7.1.5 Draft Tubes and Scroll Case, Their Importance

7.1.5.1 Draft Tube

It is a pipe of gradually increasing area which connects the outlet of the runner to the tailrace. Draft tube is used for discharging water from the exit of the turbine to the tailrace. By using it, net head on turbine is increased, hence the turbine develops more power and also the efficiency of the turbine increases. The draft tube is addition to serve a passage for the power discharge has the following purposes;

i) The draft tube helps to recover the velocity head of the water out of the runner *i.e.*, the K.E. rejected at the outlet pressure energy.

ii) The turbine may be placed above the tail race and hence inspected properly and without losing the elevation difference.

The various type of draft tube is as follows;

i) Conical draft tube
ii) Moody spreading tube
iii) Simple elbow tube
iv) Elbow draft tube with circular inlet and rectangular outlet

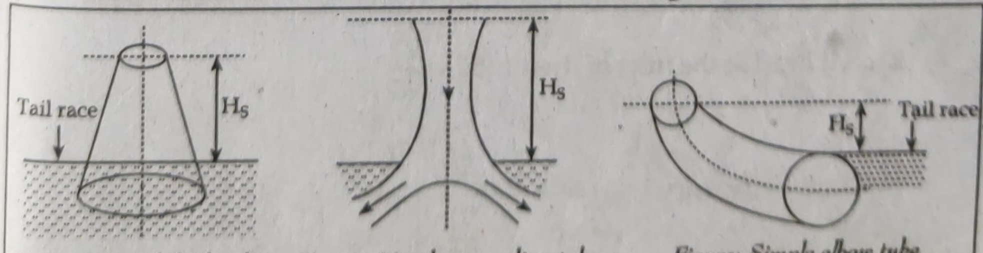


Figure: Conical draft tube *Figure: Moody spreading tube* *Figure: Simple elbow tube*

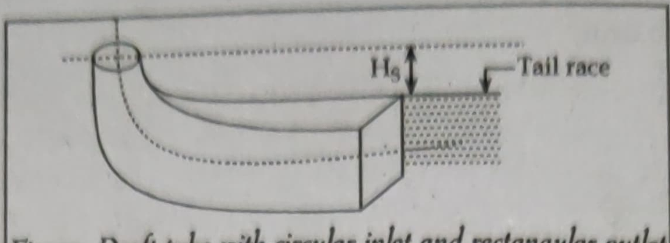


Figure: Draft tube with circular inlet and rectangular outlet

Theory on Draft Tube

Let us consider a conical draft tube as shown in the figure. Let 'y' be the distance of bottom of draft tube from tail race and H_s be the vertical height of draft tube about the tailrace.

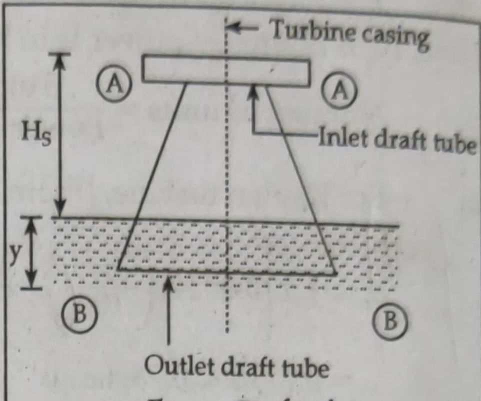


Figure: Draft tube

Now, applying the Bernoulli's equation to section A–A and B–B,

$$(H_s + y) + \frac{P_1}{\gamma} + \frac{V_1^2}{2g} = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + h_f$$

where, h_f is loss of energy between A–A and B–B.

P_1 and P_2 is pressure at A–A and B–B.

V_1 and V_2 is velocity at A–A and B–B.

We have,

$$\frac{P_2}{\gamma} = \frac{P_a}{\gamma} + y$$

where, P_a is atmospheric pressure

Thus,

$$(H_s + y) + \frac{P_1}{\gamma} + \frac{V_1^2}{2g} = \frac{P_a}{\gamma} + y + \frac{V_2^2}{2g} + h_f$$

or, $$\frac{P_1}{\gamma} = \frac{P_a}{\gamma} - H_s - \left(\frac{V_1^2}{2g} - \frac{V_2^2}{2g} - h_f\right) \quad (1)$$

In equation (1), $\frac{P_a}{\gamma} > \frac{P_1}{\gamma}$; *i.e.,* absolute pressure at the entrance of the draft tube is always less than the atmospheric pressure.

Efficiency of Draft Tube

It is defined as the ratio of actual conversion of kinetic head into pressure head and kinetic head at the inlet of the draft tube.

From the above figure; we have,

Actual conversion of kinetic head into pressure head $= \left(\frac{V_1^2}{2g} - \frac{V_2^2}{2g}\right) - h_f$

Kinetic head at the inlet of draft tube $= \frac{V_1^2}{2g}$

$\therefore$ Draft tube efficiency $(N_d) = \dfrac{\left(\frac{V_1^2}{2g} - \frac{V_2^2}{2g}\right) - h_f}{\frac{V_1^2}{2g}}$

Example 7.5

The inlet and outlet diameter of conical draft tube is 1.5 m and 2 m. The water is discharge with a velocity of 3 m/sec. at outlet. The total length of draft tube is 8 m and 2 m of the draft tube length is immersed in water. If atmospheric pressure head is 10.3 m of water and loss of head due to friction in the draft tube is equal to 0.2 times velocity head at outlet of the tube. Determine;

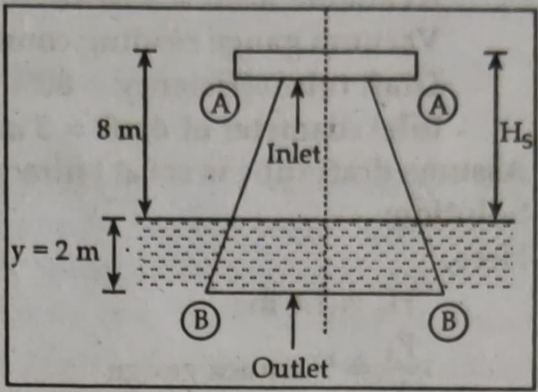
i) **Pressure head at inlet**
ii) **Efficiency of draft tube**

Solution:

i) $y = 2\text{ m}$

$H_s = 8 - 2 = 6\text{ m}$

$V_2 = 3\text{ m/sec.}$



From continuity equation; we have,

$$Q_A = Q_B$$

$$A_1V_1 = A_2V_2$$

$$V_1 = \frac{A_2V_2}{A_1}$$

where, $A_1 = \frac{\pi d_1^2}{4} = \frac{\pi \times (1.5)^2}{4} = 1.77\text{ m}^2$

$$A_2 = \frac{\pi d_2^2}{4} = \frac{\pi \times (2)^2}{4} = 3.14\text{ m}^2$$

$\therefore \quad V_1 = \frac{3.14 \times 3}{1.77} = 5.32\text{ m/sec.}$

$$\text{Head loss in draft tube} = 0.2 \times \frac{V_2^2}{2g}$$

$$h_f = 0.2 \times \frac{3^2}{2g} = 0.092\text{ m}$$

Applying Bernoulli's equation between A-A and B-B; we have,

$$\frac{P_1}{\gamma} + (H_s + y) + \frac{V_1^2}{2g} = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + h_f$$

But, $\frac{P_2}{\gamma} = \frac{P_a}{\gamma} + y$

where, $\frac{P_a}{\gamma} = 10.3\text{ m}$

or, $\frac{P_1}{\gamma} = \frac{P_a}{\gamma} + y + \frac{V_2^2}{2g} + h_f - (H_s + y) - \frac{V_1^2}{2g}$

or, $\frac{P_1}{\gamma} = \frac{P_a}{\gamma} - \left(\frac{V_1^2 - V_2^2}{2g}\right) + h_f - H_s$

or, $\frac{P_1}{\gamma} = 10.3 - \left(\frac{(5.32)^2 - (3)^2}{2 \times 9.81}\right) + 0.092 - 6$

$\therefore \quad \frac{P_1}{\gamma} = 3.41\text{ m}$

$\therefore \quad$ Pressure head at inlet = 3.41 m or, $V_1 = 9.26 \text{ m/sec.}$

$$Q_1 = A_1V_1 = Q = \frac{\pi d_1^2}{4} \times V_1 = \frac{3.1416 \times 3^2}{4} \times 9.26 = 65.45 \text{ m}^3/\text{sec.}$$

$$\text{Efficiency of turbine } (\eta) = \frac{\text{Power output}}{\gamma QH} = \frac{2800}{9.8 \times 65.45 \times 5.20} = 83.86\%$$

7.2 ELECTRO-MECHANICAL INSTALLATION

Electro-mechanical equipments are those equipments which converts the mechanical energy into electrical energy and vice versa. In the hydropower project, most of the electro-mechanical equipments are installed in powerhouse. *For example;* generators, pumps, governor, etc.

7.2.1 Generators and Their Types, Rating of Generators

7.2.1.1 Generators and their types

A generator is a device that converts mechanical energy to electrical energy for use in an external circuit. Sources of mechanical energy include steam turbines, gas turbines, water turbines, internal combustion engines and even hand cranks. The first electromagnetic generator, the Faraday disk, was built in 1831 by British scientist Michael Faraday. Generators provide nearly all of the power for electric power grids. Essentially generators are mainly two types, they are:

Synchronous Generators

Synchronous machines are principally used as alternating current (AC) generators. They supply the electric power used by all sectors of modern societies: industrial, commercial, agricultural, and domestic. Synchronous generators usually operate together (or in parallel), forming a large power system supplying electrical energy to the loads or consumers. Synchronous generators are built in large units, their rating ranging from tens to hundreds of megawatts. It converts mechanical power to AC electric power. The source of mechanical power, the prime mover, may be a diesel engine, a steam turbine, a water turbine, or any similar device. For high-speed machines, the prime movers are usually steam turbines employing fossil or nuclear energy resources. Low-speed machines are often driven by hydro-turbines that employ water power for generation. Smaller synchronous machines are sometimes used for private generation and as standby units, with diesel engines or gas turbines as prime movers.

According to the arrangement of the field and armature windings, synchronous machines may be classified as rotating-armature type or rotating-field type.

Rotating-armature type: The armature winding is on the rotor and the field system is on the stator.

Rotating-field type: The armature winding is on the stator and the field system is on the rotor.

According to the shape of the field, synchronous machines may be classified as cylindrical-rotor (non-salient pole) machines and salient-pole machines.

Asynchronous Generators

An induction generator or asynchronous generator is a type of alternating current (AC) electrical generator that uses the principles of induction motors to produce power. Induction generators operate by mechanically turning their rotors faster than synchronous speed. A regular AC asynchronous motor usually can be used as a generator, without any internal modifications. Induction generators are useful in applications such as mini hydro power plants, wind turbines, or in reducing high-pressure gas streams to lower pressure, because they can recover energy with relatively simple controls.

An induction generator usually draws its excitation power from an electrical grid; sometimes, however, they are self-excited by using phase-correcting capacitors. Because of this, induction generators cannot usually "black start" a de-energized distribution system.

Principle of Operation

An induction generator produces electrical power when its rotor is turned faster than the synchronous speed. For a typical four-pole motor (two pairs of poles on stator) operating on a 60 Hz electrical grid, the synchronous speed is 1800 rotations per minute (rpm). The same four-pole motor operating on a 50 Hz grid will have a synchronous speed of 1500 RPM. The motor normally turns slightly slower than the synchronous speed; the difference between synchronous and operating speed is called "slip" and is usually expressed as per cent of the synchronous speed. *For example;* a motor operating at 1450 RPM that has a synchronous speed of 1500 RPM is running at a slip of +3.3%.

In normal motor operation, the stator flux rotation is faster than the rotor rotation. This causes the stator flux to induce rotor currents, which create a rotor flux with magnetic polarity opposite to stator. In this way, the rotor is dragged along behind stator flux, with the currents in the rotor induced at the slip frequency. In generator operation, a prime mover (turbine or engine) drives the rotor above the synchronous speed (negative slip). The stator flux still induces currents in the rotor, but since the opposing rotor flux is now cutting the stator coils, an active current is produced in stator coils and the motor now operates as a generator, sending power back to the electrical grid.

7.2.1.2 Rating of Generators

Generator rating is set of specified values which are specified for that particular generator modify by its manufactures. It must be capable of supplying that much power output is an accurate way that is anticipated by the manufacture. Rating prove helpful while buying the product, to help in correctly selecting the machine that is needed by the user, depending upon his usage and requirement, he can choose the appropriate rating for this work. It also differentiates between the manufacturing companies and the company producers and how reliably those ratings are fulfilled by those generators. The standard units of generator rating expressed in Kilo Volt Amperes (KVA).

7.2.2 Purpose and Working Principle of Governor

The governing of the turbine is defined as the operation by which the speed of the turbine is kept constant under all working condition. It is automatically by mans of governor, which regulates the rate of flow through turbine, according to the changing load condition of the turbine. Governing of the turbines means regulating the speed of the turbine.

It is necessary as a turbine is directly coupled to an electric generator, which is required to run at constant speed under fluctuation load condition. The frequency of power generation by a generator of a constant number of pair of

...oles under varying condition should be same. The working principle of governing of Pelton turbine is shown below.

Governing of an Impulse Turbine (Pelton Wheel)

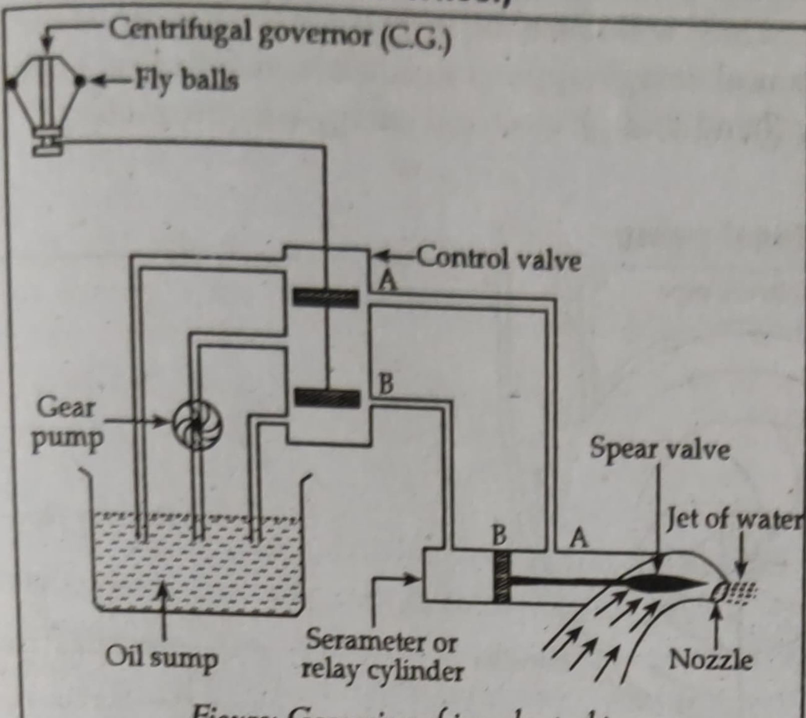


Figure: Governing of impulse turbine

For high efficiency at different loads, a speed of the turbine must be kept constant as far as possible. The process of providing any arrangement which will keep the speed constant and will regulate the rage of flow is known as governing of turbine.

- When the load on the turbine is increased it will cause the decrease in the speed of the turbine.
- As the turbine is connected to the CG by pulley, decrease in the speed of the rotation of the turbine causes the decrease in the rotation of the CG too.
- Due to that the centrifugal force on the flying ball will be decreased and ball will come down causing increase in the weight of the ball.
- Area between A and B of the control valve it's always in the pressurized condition due to the constant pumping of the fluid.
- Due to the decrease in the centrifugal force on the flying balls, lever connecting the rod of the control valve will be filled and rod of the control valve will go up. This will cause the opening of valve 'A' with still closing valve 'B'.
- The pressurized oil will rush through pipe AA and will push the piston of the servo-motor backward, causing opening of more area of nozzle.
- Opening of more area will cause more discharge on the turbine and consequently speed of the turbine will be increased.
- With the increase of speed of turbine, speed of the centrifugal governor will also be increased and weight of flying balls will be increased.
- It causes the rod of the control valve to come in the normal position and turbine acquires its normal speed.
- Similar reverse process takes place when the load on the turbine decreases. In this case control valve 'B' will be in the operation still keeping the valve 'A' closed.

7.3 PUMPS

7.3.1 Introduction to Centrifugal and Reciprocating Pumps and Their Performance Characteristics

It is the device, which will cause the increase in the energy of the flow due to the external mechanical energy applied to it. Here, mechanical energy could be the manual energy (hand pump), electrical energy (electric motor).

Types of Pump

1. **Centrifugal pump**

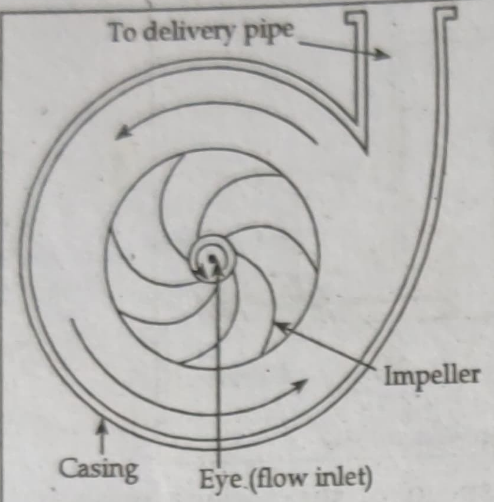


Figure: Plan of centrifugal pump

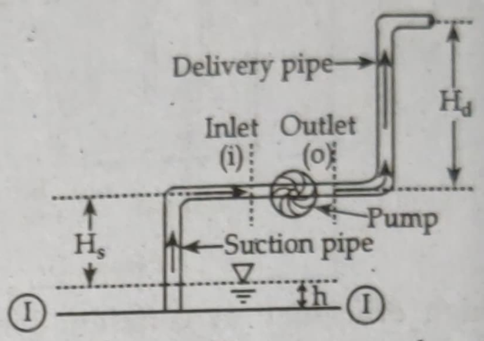


Figure: Centrifugal pump (sectional view)

The pump which raises water or a liquid from a lower level to a higher level by the action of centrifugal force is known as centrifugal pump.

Let, i and o represent inlet and outlet respectively

V_s is the velocity of flow of flow at suction pipe.

Now, writing the Bernoulli's equation between inlet section and I–I;

$$\frac{P_{atm}}{\gamma} + h + \frac{V_s^2}{2g} = \frac{P_i}{\gamma} + h + h_s + \text{Head loss at suction pipe} + \frac{V_s^2}{2g}$$

$$\therefore \quad \frac{P_i}{\gamma} = \frac{P_{atm}}{\gamma} - (h_s + \text{Head loss at suction pipe}) \qquad (1)$$

Again, writing the Bernoulli's equation between inlet and outlet section,

$$\frac{P_i}{\gamma} + \frac{V_i^2}{2g} + E = \left(\frac{P_{atm}}{\gamma} + \frac{P_0}{\gamma}\right) + \text{Head loss at delivery pipe} + \frac{V_0^2}{2g}$$

[$\therefore$ E = Energy head imparted by the motor]

or,
$$\frac{P_{atm}}{\gamma} - h_s - \text{Head loss at suction pipe} + \frac{V_i^2}{2g} + E = \frac{P_{atm}}{\gamma} + \frac{P_0}{\gamma} + \text{Head loss at delivery pipe} + \frac{V_0^2}{2g}$$

$$\therefore \quad E = \text{Total head } (H_T) = H_a + H_s + (\text{Head loss at suction pipe} + \text{Head loss at delivery pipe}) - \frac{V_i^2}{2g} + \frac{V_0^2}{2g}$$

2. **Reciprocating pump**

Main components

- Cylinder (C) contains the piston, which could be move forward and backward through the rotating crank with the help of connecting rod.

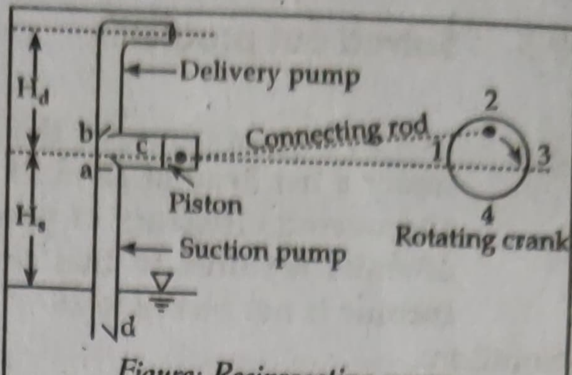


Figure: Reciprocating pump

- Suction pipe connects the source of water and cylinder.
- Delivery pipe supplies the discharge from the cylinder.
- Suction valve 'a', which allows the flow from the source to the cylinder and does not allow from the cylinder to the suction pipe.
- Suction valve 'b', which allows the flow from the cylinder to the delivery pipe and does not allow the reverse flow.
- Valve 'd', which will hold the water at the suction pipe, even the pump is not in operation.

Working principal

- During the suction stroke, piston moves to the right hand side (position 1-2-3), which creates the vacuum in the cylinder.
- This cause the valve 'a' to open and flow enters the cylinder.
- When the piston moves to the left hand side (position 3–4–1), this cause the increase of the pressure in the cylinder.
- Due to the increase of the pressure valve 'b' will be opened and valve 'a' will be closed, so water will be discharge through the delivery pipe.

7.4 Cavitation

The vapour filled bubbles are called cavity and presumed to form around a dust nuclei, which may be present in the liquid. These bubbles are carried along by the flow to high pressure regions, where the vapour condenses and bubbles suddenly collapse. The surrounding liquid then rushed from all direction collides at the CG and a high pressure of around 1000 atm is generated. The entire phenomenon of formation, growth, travel and collapse of bubbles is referred as cavitation.

Effect of cavitation

- Considerable cracking or rattling may be produced leading to objectionable variations.
- Pressure velocity distribution in this effected region is greatly destroyed.
- Due to the vibration and pitting, the efficiency of hydraulic machinery will be reduced.
- The metallic and concrete walls containing the water stream may be severely damaged.

The cavitation is harmful as it affects the hydraulic machines in following ways;

- Loss of material due to pitting.
- Pitting and erosion of metal parts.
- Reducing the actual volume of liquid due to formation of bubbles.
- Knocking vibration and noise the machine parts.

The cavitation effects can be reduced by following ways;

- Setting the turbine near the tail race.
- The velocity should be controlled so as not to exceed a safe limit.
- Making the runner blade and interior face of draft tube from especially chosen resistant material.